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TUNGSTEN ELECTRON EMITTER (TE²) WITH DIRECT HEATED CATHODE BY PLASMA STREAM

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Abstract

At Goethe-University, a novel concept of heating metallic cathodes is currently under investigation. In the scope of the ARIES collaboration WP16, an RF-modulated electron gun was developed and manufactured for application in electron lenses for space charge compensation. The goal of this project is to increase the intensity of primary beams, especially in low energy booster synchrotrons like the SIS18 and SIS100 at GSI/FAIR or the SPS at CERN. The gun was designed to produce electron currents of 10 A at extraction voltages of 30 kV. The tungsten electron emitter (TE²) and the grid electrode were designed and manufactured to be integrated in the extractor of the original volume type ion source. Significant effort was put into a robust and flexible design with highly reliable key components. The cathode is heated by a plasma stream generated in the plasma chamber of the source. Different heating options of the cathode are currently being studied. This contribution presents the working principles of the electron gun and first measurements results of cathode heating.

INTRODUCTION

Common electron sources use oxide cathodes or photo cathodes for electron beam production [1]. Some exotic cathode materials are currently used [2]. All of these technologies are less robust against vacuum contamination, vacuum discharges (Townsend discharge) and secondary particle impact. Therefore, it was decided to use a pure tungsten cathode for the production of the intense electron beam with an emission density of J = 0.453 $\mathrm{Acm^{-2}}$. The heating of the cathode is challenging, as a temperature range of 2200-2800 °C is needed for an adequate electron emission following Richardson's law. Inspired by the concept of hybrid ion sources [3], the direct heating of the cathode by the use of a plasma stream, generated by an arc discharge, was used. For the proof of concept, an existing gas discharge ion source was modified and the plasma electrode was replaced by a tungsten cathode. The flexibility of the plasma generator enables the guiding of the arc discharge to the cathode and the variation of arc power and power density distribution on the cathode. The resulting high cathode temperatures need an effective cooling of cathode and grid flange. On the other hand thermal conductivity determines the temperature distribution on the extraction surface. A careful layout of stainless steal thermal spacers led to heat balance and resulted in the desired temperature distribution. The spacers were mounted to connect the water cooled cathode flange and the tungsten cathode.

Three options to create a time structure on the extracted electron beam were discussed. The first one is a pulsed extraction voltage. This option is not favourable because of beam mismatch and the high power load. A pulsed arc discharge, leading to a pulsed heating of the cathode, is only suitable for duty cycles of a few percent with low pulse frequencies due to the thermalisation time of the cathode. Therefore, a grid modulated beam extraction is used. A high voltage modulation can be applied to synchronise the time structure of the electron beam with the ion bunch evolution during a synchrotron cycle. A careful layout protects the grid from heat load and provides a cut-off frequency of about 600 MHz. The design of the electron source presented in this paper was chosen to be the prototype of the IRME-gun [4,5]. Additionally, a research project was started for the investigation of electron emission of metal surfaces in the near of the phase transition.

DESIGN OF THE ELECTRON GUN AND TEST STAND

The design of the electron gun TE² is based on an existing volume type ion source. All parts are optimized regarding water cooling, high voltage break downs, vacuum conditions and outside isolation [6,7].

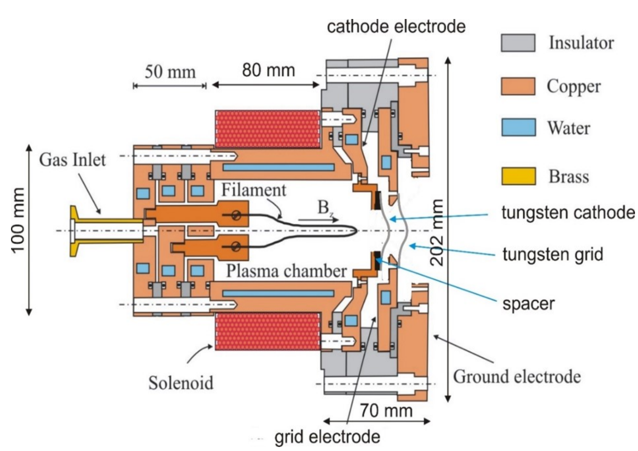

Figure 1: Cross sectional view of TE².

The ion source design was transformed into an RF modulated electron gun by replacing the plasma electrode by a copper cathode flange with tungsten cathode. The screening electrode of the former accel-decel extraction system was replaced by a grid flange with tungsten grid. The ground elec-

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trode was shaped for an optimal beam matching (see Fig. 1). In a first step, cathode and grid are shaped to gain a Gaussian

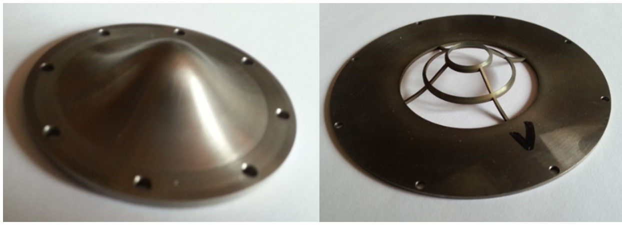

Figure 2: Left: robust tungsten cathode with a purity factor of 99.98 %, Right: grid for beam modulation.

electron density distribution, but all parts are mounted as flexible as possible (see Fig. 2). Different shapes of cathode and grid can be investigated in the future as well as hollow or elliptical cathodes. Therefore, TE² is well suited as a test device for innovative electron beam extraction schemes.
The plasma generator is electrically insulated against the cathode flange, and enables different modes for the arc discharge as shown in Figure 3. On the left hand side both, plasma generator and cathode are biased with the same arc voltage leading to an arc discharge with a centered plasma stream in the middle of the plasma chamber. A floating of the cathode shifts the plasma stream in the direction of the cathode (middle), whereas a floating of the plasma chamber shifts the plasma stream in the opposite direction. The direction of the plasma stream, as well as the arc discharge power, can be manipulated by applying a small potential difference between the plasma generator and cathode. Additionally, the total heating power can be adjusted with discharge current and working gas pressure. The hole electron source is embedded in an axial magnetic field of a solenoid to produce intense magnetised electron beams.

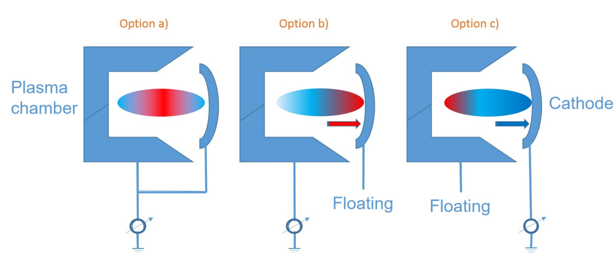

Figure 3: Three different modes to connect plasma chamber and cathode for manipulation of the arc discharge.

The influence of the magnetic field on the plasma stream has to be studied in detail.
TE² was integrated in a test bench to proof the concept of cathode heating, to evaluate the performance with respect to thermal stress and electrical insulation (see Fig. 4). GSI/FAIR provided two solenoids with a maximum field strength of 0.6 T to the experiments. The first solenoid houses the electron source, and the second one is connected to the diagnostic chamber. The latter is equipped with a faraday cup, a ccd-camera for optical inspection of the cathode and grid as well as a pyrometer for the measurement of surface temperature distribution. TE² is connected with a high voltage terminal, which can provide an electric power up to 20 kW and a beam loading 4 kW. Therefore in the future, the second solenoid will house the beam dump with power recovering system.

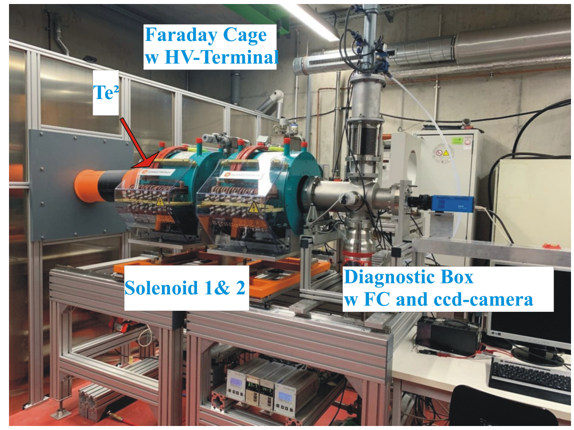

Figure 4: HV-Terminal with connection to the beamlines. TE² is inside the first of the two solenoids. The diagnostic chamber is equipped with a Faraday-cup, a camera and pyrometer.

PLASMA IGNITION

TE² uses a hot filament driven gas discharge for plasma production. The filament is a Tungsten wire with 1mm in diameter which produces a small amount of electrons to fulfil Paschen's law. Therefore it has to be heated with a power of 780 W. First experiments using air as working gas showed a degradation of the cathode-plasma interaction surface, by layers of tungsten carbide and tungsten blue, which indicate temperatures between 700 and 1400 °C at the surface. In the next step, Argon was used, but the degradation of the filament by sputtering reduced the life time of the filament. Finally, Helium is used as a inert gas with a moderate sputter coefficient and the gas pressure is 0.01 hPa. No degradation of the surfaces, neither at the plasma chamber non at the cathode was observed. The aging of the filament is estimated by the control system by measuring the filament resistance continuously and it predicts the time still left till the next maintenance. After replacing the filament with a new one, a baking routine is necessary to prevent microscopic cracks, which in turn reduces the life time of the filament. In future, it is planned to investigate an RF driven gas discharge for plasma stream production to overcome the disadvantages of the use of a hot filament.

CATHODE HEAT-UP

The heat-up of the cathode was observed by the use of a ccd-camera. Figure 5 shows two images of the cathode at different temperatures. The image of the "cold" one at 850 K was used to evaluate the adjustment of the plasma stream in the center of the cathode area to provide a symmetric electron density distribution. The given temperature

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Figure 5: An example of cathode heat-up measurement and proof of principle, measured temperature given at emissivity factor $\varepsilon = 1$.

was measured by the use of the pyrometer in the center of the cathode. The change of the color across the cathode indicates the temperature gradient. This will be verified in a next step by the use of a pyrometer with an spatial resolution of 1 mm². The grid is visible clearly in front of the cathode. After increasing the arc discharge power, the temperature of the cathode increases up to 1875 °K. Due to the high luminescence, it was not possible to observe a temperature gradient as well as the heat-up of the grid.

In a next step, different modes for the gas discharges were

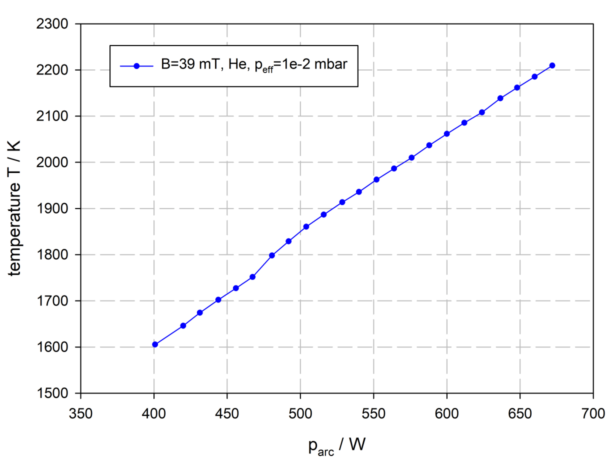

Figure 6: Power of the arc discharge as a function of the temperature measured with pyrometer at a magnetic field of 39 mT and Helium gas with a residual gas pressure of 0.01 hPa.

investigated. The mode using the floated cathode was found to be most efficient. The cathode temperature for this mode is plotted as a function of arc discharge power in Fig. 6 and shows a nearly linear behaviour. This facilitates the adjustment of cathode temperature, and therefore the electron beam current by the control system.

Direct heating using a plasma stream may suffer under fluctuation in the arc power and plasma density. The control system of TE² stabilizes the arc power to provide constant surface temperatures and therefore constant electron currents. Figure 7 shows a histogram of the arc power recorded for low median arc power of 280 W for test of the control loop. A variation of $\Delta P = \pm 1.5\,\%$ was observed over a time of ten minutes and the control frequency was chosen to be 10 Hz. Experiments emphasizing long term stability and reliability are planned, and will show the impact on the electron current fluctuation of the extracted electron beam.

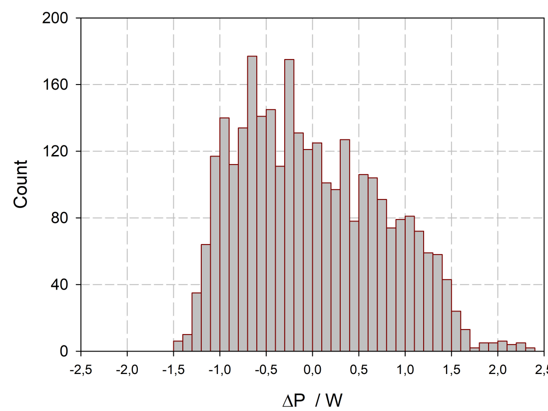

Figure 7: Arc power stabilisation by the TE² control system.

CONCLUSION

TE² was designed to use a new concept for direct heating of robust metal cathodes. Experiments show that it is possible to reach temperatures suitable to extract high intensity electron beams. The flexibility of the technical layout enables a variation of different cathode and grid shapes, which will be important for the development of e-lenses for space charge compensation or hollow e-lenses for beam collimation. Furthermore, TE² enables the research on electron emission in the near of phase transitions or plasma chemistry.

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REFERENCES

[1] Joseph A. Eichmeier, Manfred K. Thumm, *Vacuum Electronics*, Springer Berlin, Heidelberg 2008. doi:10.1007/978-3-540-71929-8

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[2] A. Pikin *et al.*, “Nonadiabatic electron gun at an electron beam ion source: Commissioning results and charge breeding investigations”, *Phys. Rev. Accel. Beams*, vol. 25, p. 013402, 2022. doi:10.1103/PhysRevAccelBeams.25.013402

[3] R. Keller *et al.*, “A hybrid ion-source concept for a proton driver front-end”, in *AIP Conference Proceedings*, vol. 773, p. 104, 2005. doi:10.1063/1.1949506

[4] K. Schulte-Urlichs *et al.*, “D16.3 - Tests of electron gun at test stand completed”, ARIES Milestone Report, Draft 2021, unpublished.

[5] K. Schulte-Urlichs *et al.*, “Status of the Development of the Electron Lens for Space Charge Compensation at GSI”, presented at the IPAC’22, Bangkok, Thailand, Jun. 2022, paper WEPOTK003, this conference.

[6] N. Joshi, M. Droba, O. Meusel, and U. Ratzinger, “Characterization of volume type ion source for p, H2+ and H3+ beams”, *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 606, no. 3, pp. 310–313, 2009. doi:10.1016/j.nima.2009.05.008.

[7] K. Schulte-Urlichs *et al.*, “Status of the Electron Lens for Space Charge Compensation in SIS18”, in *Proc. IPAC’21*, Campinas, Brazil, May 2021, pp. 1880–1883. doi:10.18429/JACoW-IPAC2021-TUPAB200